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New Insights Into the Origin and Evolution of the Hikurangi Oceanic Plateau

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Oceanic plateaus and continental flood basalts, collectively referred to as large igneous provinces (LIPs), represent the most voluminous volcanic events on Earth. In contrast to continental LIPs, relatively little is known about the surface and internal structure, range in age and chemical composition, origin, and evolution of oceanic plateaus, which occur throughout the world's oceans [e.g., *Mahoney and Coffin*, 1997].

One of the major goals of the R/V *Sonne* SO168 ZEALANDIA expedition (depart Wellington, 3 December 2002, return Christchurch, 15 January 2003) was to investigate the Hikurangi oceanic plateau off the east coast of New Zealand.

Detailed multi-beam mapping and sampling carried out on this expedition yielded one of the most detailed bathymetric maps and rock collections of an oceanic LIP to date. The new maps reveal spectacular views of one of these massive volcanic events on the seafloor, providing new insights into the geodynamic evolution of the Hikurangi Plateau. The investigations provide further support that the Hikurangi and Manihiki LIPs may have once formed a single plateau, covering an area of ~900,000 km^2 (similar in size to Germany and France combined), but were subsequently rifted apart.

Large igneous provinces are commonly believed to have formed over relatively short time scales (several million years) through massive, mushroom-shaped mantle upwellings associated with the initial stages of mantle plumes [*Richards et al.*, 1989]. Alternative hypotheses include formation through plume-ridge interaction [e.g., *Mahoney and Spencer*, 1991], large-scale melting triggered by meteoritic impacts [e.g., *Rogers*, 1982], and accumulation and amalgamation of multiple intra-plate volcanic structures into a LIP through the subduction process [e.g., *Hoernle et al.*, 2004].

The triangular-shaped Hikurangi Plateau covers 350,000 km^2 (similar in size to New Zealand) and is located ~2500–3500 m below sea level (Figure 1a). The northwest margin is being subducted beneath the North Island of New Zealand, and the southern boundary may have been partially subducted beneath the Chatham Rise [*Davy and Wood*, 1994]. The northeast margin of the plateau is adjacent to Cretaceous Pacific sea floor located at a depth of ~4.5–5.5 km.

Geophysical investigations [e.g., *Wood and Davy*, 1994] suggest that during its formation, 3–5 million km^3 of volcanic rocks were erupted on the seafloor. This volcanism may have been even more extensive if the Hikurangi Plateau was once connected to the Manihiki LIP (now located ~3000 km to the north), but separated in the Cretaceous by seafloor spreading at the Osbourn Trough (Figure 1a), a paleo-spreading center [*Billen and Stock*, 2000]. It has also been suggested that the Manihiki Plateau may have formed as part of a "greater Ontong Java Plateau event" [*Coffin and Eldholm*, 1993], which may have covered nearly 1% of the Earth's surface. Whether separate events or a single mega-event, the volcanism associated with these three oceanic plateaus must have had a dramatic impact on the chemistry, temperature, and life in the Pacific Ocean.

During the ZEALANDIA expedition, 20 large seamounts and a large portion of the northeastern margin of the Hikurangi Plateau were mapped using a SIMRAD EM120 multi-beam echo-sounding system and sampled by dredging. This article discusses the most interesting morphological features of the plateau: (1) the northeastern margin, including the Rapuhia Scarp; (2) large, guyot-type seamounts, which occur primarily within the plateau; and (3) ridge-type volcanic seamounts, which occur along the northeastern margin of the plateau.

Northeastern Plateau Margin

The northeastern edge of the Hikurangi Plateau rises up to 1000 m above the Cretaceous Pacific abyssal plain. The northernmost 150 km of this margin, known as the Rapuhia Scarp, forms a steep (up to 35°) linear slope trending at 135°. The multi-beam mapping showed that the Rapuhia Scarp does not form a single scarp but generally consists of multiple steps or terraces, interpreted to represent step-faulting. The greatest vertical height of a single scarp was ~800 m, which permitted sampling of the interior of the plateau. Recovered igneous samples included non- to slightly vesicular basalts, dolerites, gabbros, and volcaniclastic rocks with tholeiitic and alkali basaltic to trachybasaltic compositions.

Interior Guyot-Type Seamounts

The large seamounts in the interior of the plateau rise 1000–1650 m above the plateau floor, representing a late stage in the evolution of the plateau. The most striking feature of all the seamounts is their guyot-like form, characterized by circular, steep-sided bases and a relatively flat top (up to 24 km across with ≤ 400 m variation in height from the margin to the center, Figures 1b and 1c). Volcanic cones (Figures 1b and 1c) are common on these seamounts; volcanic rift systems, extending up to 20 km from the base of the guyots (Figure 1b), also occur. Pillow lavas and sheet flows were clearly recognizable through video observation with a TV grab. Rock samples from the seamounts range from lavas and volcaniclastic breccias, to sandstones and conglomerates. The swath mapping and recovered samples are consistent with the seamounts being the bases of former island volcanoes, with the flat tops having been formed by erosion of the island to sea level.

The depths of the erosional platforms beneath sea level range from 1600 to 3300 m, indicating that the Hikurangi Plateau underwent substantial subsidence after formation of these seamounts. Small cones located on many of the erosional platforms must have formed after the former island volcanoes subsided below wave base. As is the case with the depth of the platforms, the depth of the seafloor at the base of the volcanoes (2600–4200 m) also increases systematically to the northeast (Figure 1d). The height of the platform above the surrounding seafloor is relatively constant at ~1050 m.

The simplest explanation for the similar height of the erosional platforms above the seafloor (despite systematically increasing water depths of the surface of the plateau toward the northeastern margin) is that the top of the Hikurangi Plateau was roughly horizontal when the former island volcanoes were eroded to sea level, and that major differential subsidence occurred after all seamounts were eroded to sea level. Assuming an average sediment thickness of ~400 m on the surface of the plateau, as suggested by seismic data [*Wood and Davy*, 1994], the surface of the plateau would have been located at a depth of ~1500 m at the

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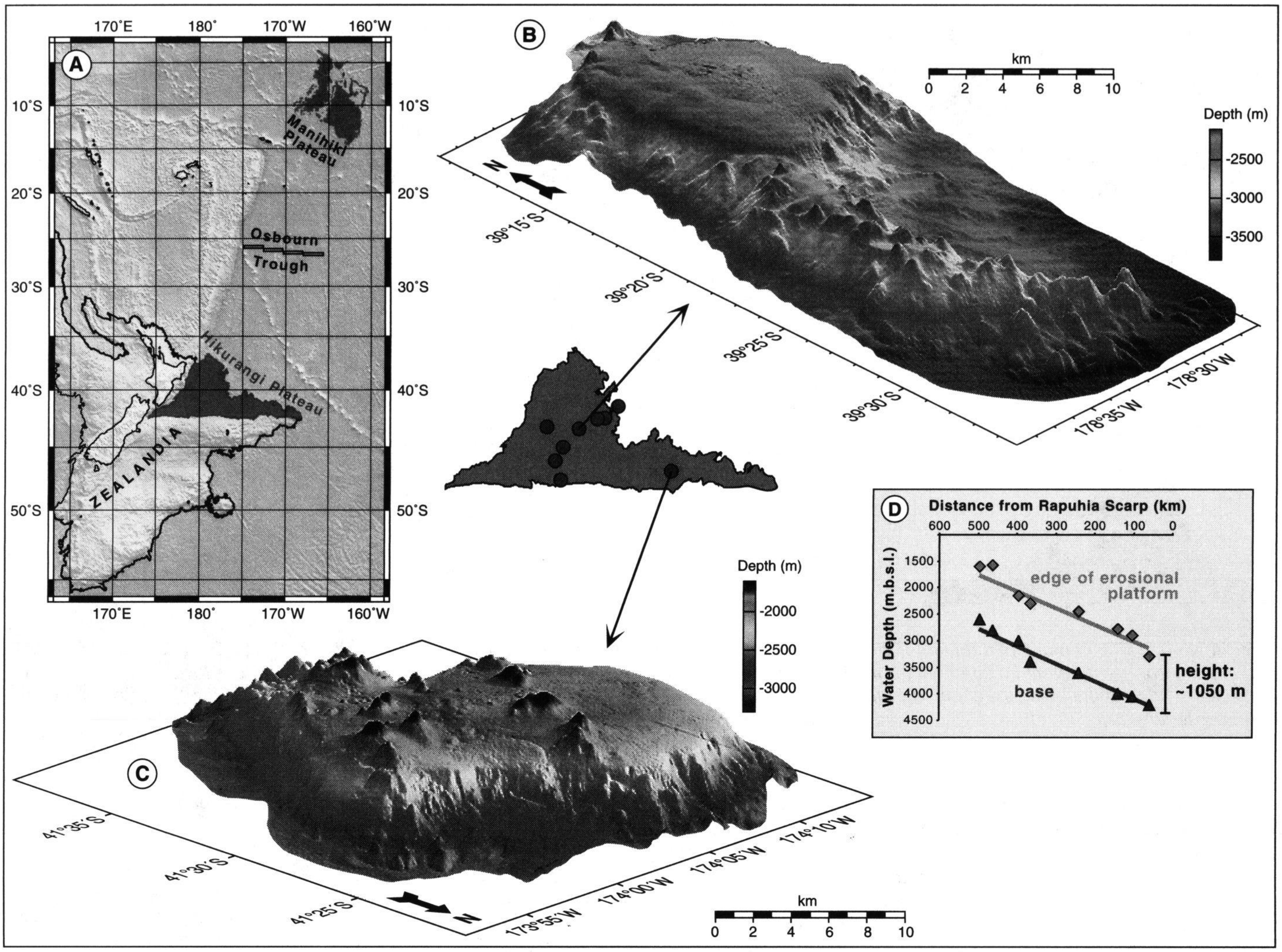

Fig. 1. Overview map and typical examples of the guyot-like seamounts in the interior of the Hikurangi Plateau. (a) Bathymetric map of the southwestern Pacific showing the locations of ZEALANDIA (New Zealand micro-continent), the Hikurangi and Manihiki large igneous provinces (LIPs), and the Osbourn Trough (paleo-spreading center) halfway between the two plateaus. (b and c) Bathymetric maps display typical guyot-type seamounts (characterized by steep flanks and a flat top) on the Hikurangi Plateau. In Figure 1b, a curvilinear constructional volcanic rift system with abundant cones on its top and flanks extends 20 km southward from the main volcanic shield. The base of the seamount in Figure 1c measures 20 by 25 km; post-erosional cones rise up to ~250 m above the erosional platform. (d) Plot of the water depth of the edges of the erosional platforms and of the bases of the mapped guyot-type seamounts on the Hikurangi Plateau versus their distance from the northwestern plateau margin. The height of the platforms from the seafloor is roughly constant at ~1 km, whereas the base of the seamounts becomes systematically deeper to the north. Original color image appears at back of this volume.

time the volcanic island province was eroded to sea level.

Marginal Ridge-Type Seamounts

The ridge-type seamounts are morphologically distinct from the guyot-type seamounts and comprise elongated linear features with sharp tops (Figure 2). These seamounts occur exclusively along–that is, within 70 km of–the northeastern margin of the Hikurangi Plateau. On the northwestern part of the margin, the mapped ridges trend north to north-northwest, and are sub-parallel to the plateau margin. Dredging yielded scoriaceous and palagonitic volcanic breccias and highly vesicular basaltic lavas, similar to those from the post-erosional volcanic rocks on the guyots.

The ridge-type seamounts reach elevations of up to 1500 m above the seafloor, which exceeds the height of the erosional platforms above the seafloor on the guyots (850–1225 m), but are similar to the elevations of the post-erosional volcanism (cones and lava fields) on the guyots (up to 1650 m above the seafloor). Therefore, at least the latest stages of volcanism on some of the ridge-type volcanic seamounts, similar to the post-erosional volcanism on the guyots, formed after the interior seamounts were eroded to sea level and began to subside. The composition of all the seamounts is more Si-undersaturated than the plateau lavas, and range from alkali basalts through mugearites to basanites, and tephrites to nephelinites. The post-erosional and ridge-type seamounts generally have the most Si-undersaturated compositions.

Some of the volcanic ridge-like seamounts occur along the scarp forming the northeastern plateau margin, whereas other ridges occur more than 65 km within the plateau (Figure 2). The linearity of these ridge-type seamounts, their proximity to the northeastern margin, and their orientation sub-parallel to the margin suggest that these seamounts occur in association with extensional faults. The volcanism must have occurred contemporaneous to faulting, since the flanks of the ridge-type seamounts are displaced along some of the margin. In conclusion, the swath mapping suggests that volcanism was related to the formation of the rifted northeastern Hikurangi margin, most likely resulting from the breakup of the paleo Hikurangi-Manihiki Plateau.

Working Hypothesis

The swath bathymetry and recovered samples suggest the following sequence of events in the geodynamic evolution of the Hikurangi Plateau. After the formation of most of the plateau, a province of ~20–25 ocean island volcanoes formed, probably similar in size and height, or possibly even bigger, than the youngest Hawaiian volcanoes. These volcanic islands went through their growth and erosional stages when the plateau surface was sub-horizontal,

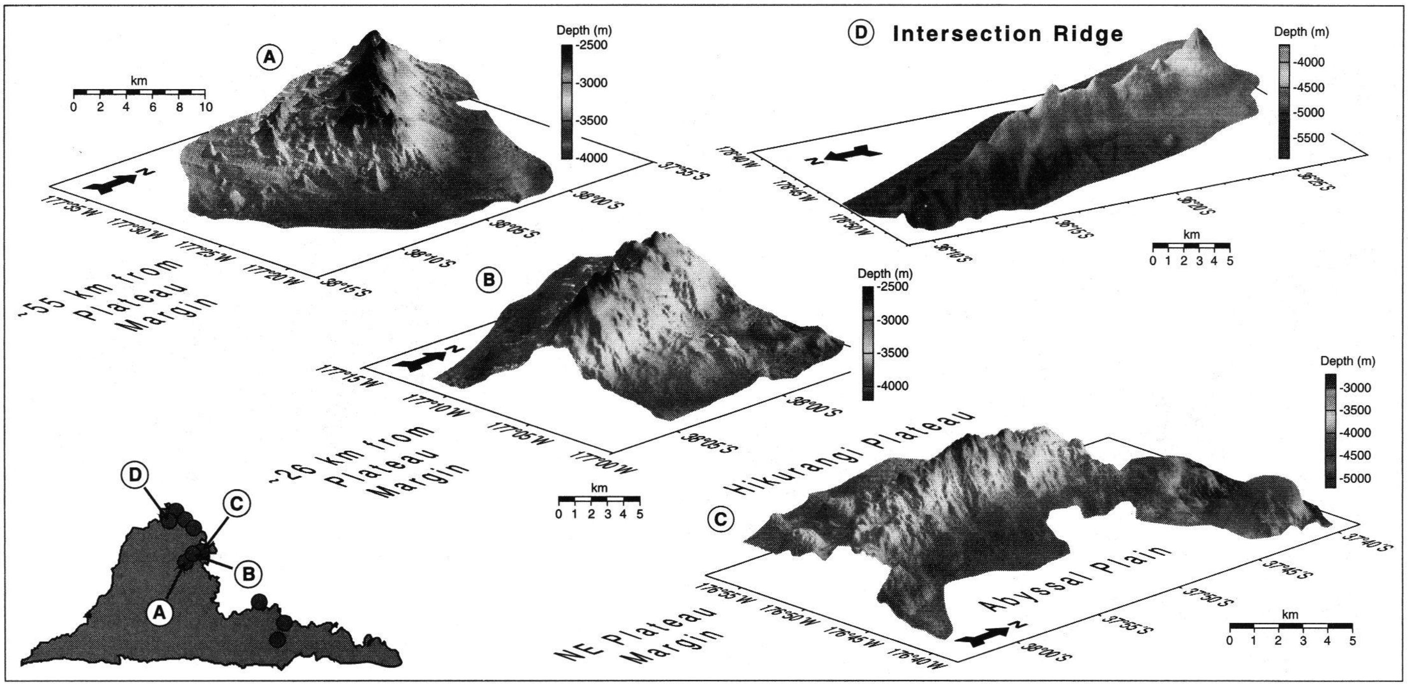

Fig. 2. Swath bathymetry maps of marginal ridge-type seamounts on the Hikurangi Plateau with north to north-northwest orientations. Going from southwest to northeast, Figure 2a is ~55 km from the plateau margin, Figure 2b is ~26 km from the margin, and Figure 2c is located directly on the northeastern edge of the plateau. Figure 2d: Southernmost 22 km of the 45-km-long, north-northwest-striking Intersection Ridge. Swath mapping and sampling demonstrated that it consists of a chain of coalesced volcanic cones. Original color image appears at back of this volume.

located at a depth of ~1500 m. After all the islands were eroded to sea level, the plateau began subsiding. The post-erosional volcanism on the platforms of the guyots and extensional faulting in the vicinity of the northeastern margin, which allowed magmas to rise to the surface forming the ridge-type seamounts, occurred in shallow water during the initial stages of subsidence. The extensional faulting could have been related to breakup of the combined Hikurangi-Manihiki Plateau by seafloor spreading along the now extinct Osbourn Trough spreading center. After breakup, the Hikurangi Plateau continued subsiding with the northeastern boundary subsiding at least 1700 m more than the southwestern part, resulting in tilting of the Hikurangi Plateau to the northeast.

The increasing Si-undersaturation and alkalinity of the volcanic rocks with decreasing age suggest that the degree of melting decreased and melting depths increased during the waning stages of plateau growth. Radiometric age-dating and petrologic and geochemical studies, currently under way, will help test the chronology of events proposed here and test a common origin for the Hikurangi and Manihiki Plateaus.

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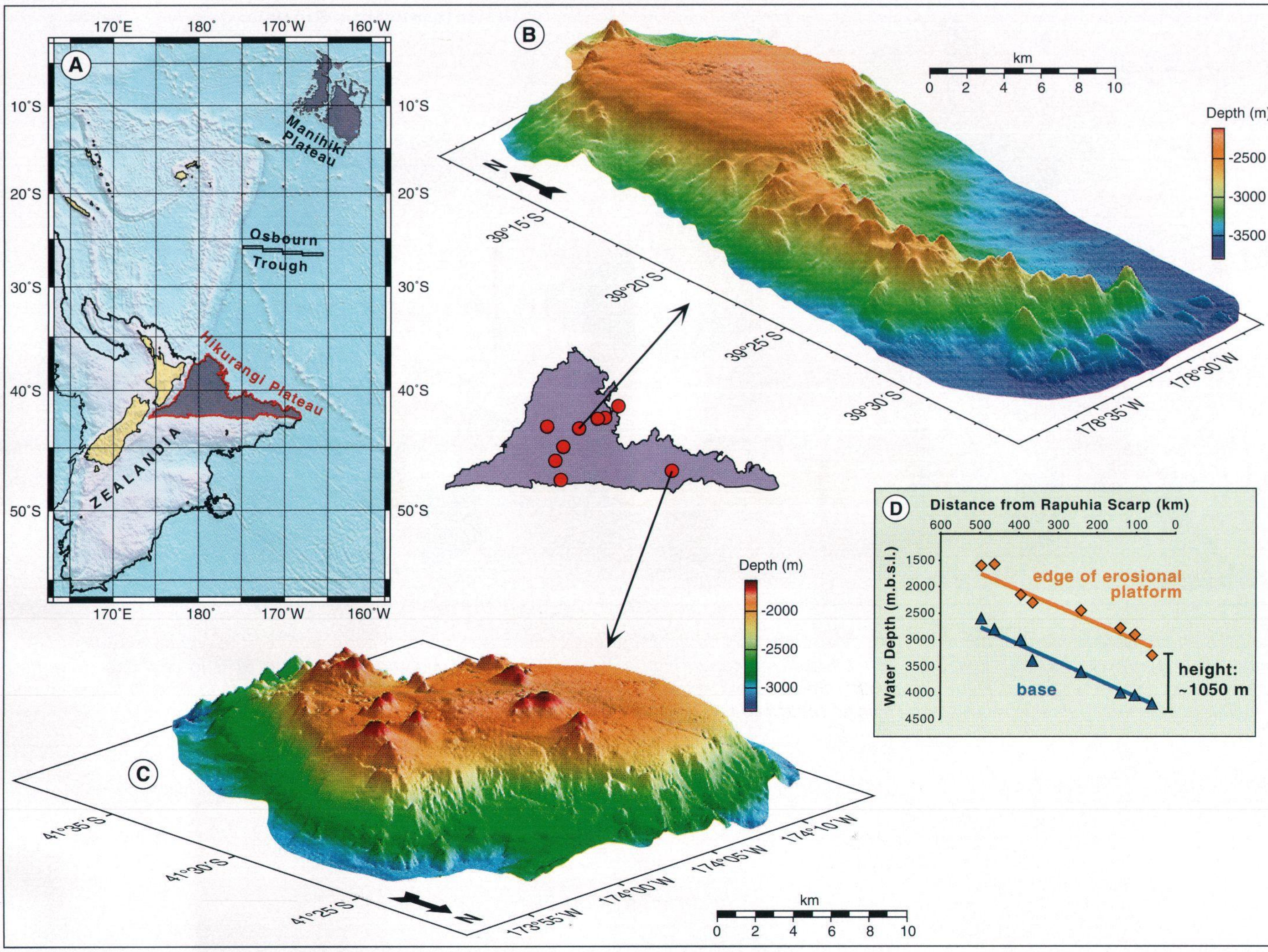

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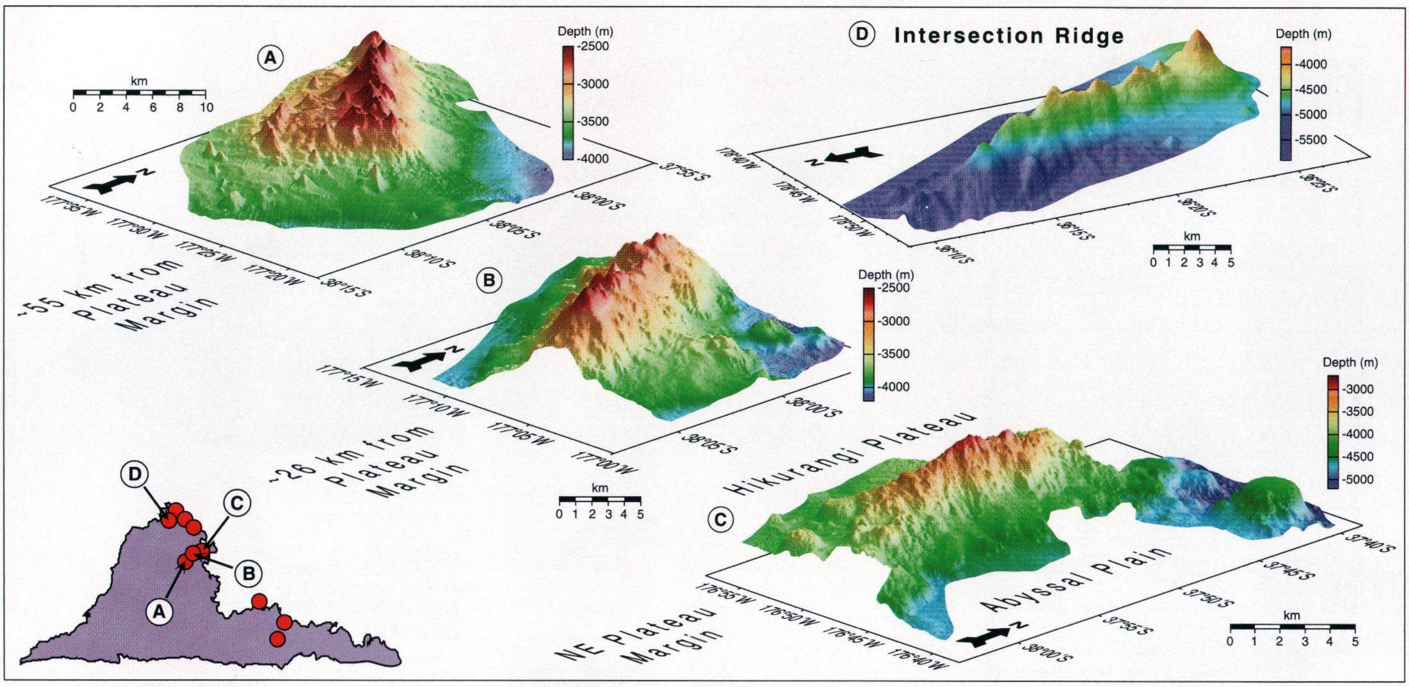

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